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DIGITAL MODEL OF THE MEAN ANNUAL TEMPERATURE AND PRECIPITATION IN MACEDONIA

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ABSTRACT

In this paper, an approach of GIS-based modelling of mean annual temperature and precipitation in Macedonia is presented. The approach is based on the vertical temperature and precipitation gradients calculated from the 30 meteorological stations in the country and implemented over detailed 15-m DEM. Final raster models show very good accuracy when compared to previous models and iso-maps, because of normalization with real data which is made in the second stage of the procedure. Originally, both of the models (the mean annual temperature and precipitation), have 100 m spatial resolution, but they can be resampled according to the needs and purposes of further work.

Key words: climate, temperature, precipitation, GIS.

INTRODUCTION

The need of accurate digital map of mean annual temperatures and precipitations today is necessary for each region and country and for variety of purposes. In the past, a number of traditional (hardcopy) and digital maps were created for the area of the Republic of Macedonia. With traditional approach, several expert-based iso-maps were created according to the available data from the meteorological stations and the relief topography. This approach was accurate on the meteorological sites and its vicinity, but further significantly diminished. Also, the maps were in hardcopy with extremely low spatial resolution. The newer approach (last 2 decades) relies on digital DEM-based interpolation of temperature and precipitation according to the vertical gradients, usually defined by the regressions of renowned Macedonian meteorologist A. Lazarevski (1993) for the period 1951-1980. The problem here is that this author distinct 5-6 regions with different values of vertical gradients and thus distinct regressions. The difficulty of merging of these isolines for distinct regions appears or the grid is only partially accurate if only the gradients for the largest region were used. In the same time, several regional and even global high-scale climate grids appear, from which WorldClim (Hijmans et al., 2005) is one of the most detailed. The WorldClim interpolated climate layers were made using major climate databases for the period 1960-1990 and 1950-2000 compiled by the Global Historical Climatology Network (GHCN), the FAO, the WMO, the International Center for Tropical Agriculture (CIAT), R-HYdronet, and a number of additional minor databases. For the topography gradients, SRTM30 elevation database (30" or 1 km) is used. Climate modeling in WorldClim is made with ANUSPLIN software for interpolating noisy multi-variate data using thin plate smoothing splines. The data layers were generated through interpolation of average monthly climate data from weather stations on a 30 arc-second (1 km) resolution grid. After removing stations with errors, the used database consisted of precipitation records from 47,554 locations and mean temperature from 24,542 locations worldwide. For the area of Macedonia, 9 stations were used (Kriva Palanka, Štip, Demir Kapija, Prilep, Bitola, Skopje, Petrovec, Ohrid and Lazaropole). Thus, large regions in eastern, SE and NW part of the country are not covered with stations data.

METHODOLOGY

Because of aforementioned problems an approach of raster grid creation is used with combination of real data from meteorological stations and vertical gradients. First of all, exact position of 30 meteorological stations is determined and plotted on the map (according to its given coordinates) as a vector points. For each point (meteorological station) the mean annual temperature and precipitation sum for the standard period 1961-1990 is entered as attribute value according to the data of Zikov et al., 1997. For those stations without complete data, the period 1951-1980 is used according to the data of Lazarevski (1993). Because of the border area consistency, available data from the 8 near stations in neighbour countries (Bulgaria, Greece, Albania, Kosovo and Serbia) were added also in procedure. The next step was gridding (rasterization) of vector-based data. After detailed checking and analysis, gridding from points is performed using Modified Quadratic Shepard module in SAGA GIS v2. The produced grid is checked well for consistency and accuracy. Also, regression analysis is made for temperature and precipitation as a scatterplot in regard to the 15 m DEM of the Republic of Macedonia. In such way, suitable regressions were calculated and compared with regressions of Lazarevski (1993). With these regressions, raster grids of mean temperature and precipitation based on vertical gradients were generated. Final models are produced with averaging of grids of interpolated real data and vertical gradient grids. Resolution of the maps for practical purposes is reduced to 100 m which is considered as fairly enough for general purposes (Fig. 2).

RESULTS

100 m grid models of the mean annual temperature and precipitation of the Republic of Macedonia consists of nearly 2.53 million points covering the country area. The results show that the mean annual temperature in Macedonia is in range from 0.2°C to 14.6°C with average of 9.9°C. It is slightly higher than the values from the WorldClim (period 1950-2000), with the range from 0.03°C to 14.6°C and 9.7°C as average. The precipitation grid shows range from 444 mm to 1103 mm with 660 mm of average which is bellow the values of WorldClim (443 mm to 1173 mm and 730 mm of average).

Table 1. Mean annual temperature (T) and precipitation (P) data for meteorological stations in Macedonia (1951-1980; 1961-1990 and 1985-2014*).

	T 51-80	T 61-90	T 85-14*	P 51-80	P 61-90	P 85-14*
Berovo	**8.7**	**8.6**	**9.2**	**647.2**	**599.0**	**637.3**
Bitola	**11.0**	**11.0**	**11.7**	**599.8**	**609.0**	**628.2**
Brod	**10.7**	**10.3**	**-**	**735.1**	**686.0**	**-**
Debar	**11.8**	**-**	**-**	**872.2**	**889.8**	**-**
Delčevo	**10.6**	**10.6**	**11.1**	**570.1**	**514.7**	**560.0**
D. Kapija	**13.8**	**13.5**	**14.2**	**586.7**	**561.0**	**567.7**
Ergelija	**12.9**	**12.6**	**12.9**	**471.9**	**492.0**	**482.5**
Gevgelija	**14.0**	**14.0**	**14.8**	**675.5**	**671.0**	**690.7**
Kavadarci	**13.6**	**-**	**13.9**	**476.7**	**-**	**458.0**
Kičevo	**10.8**	**10.7**	**11.1**	**786.7**	**764.0**	**761.0**
Kočani	**12.9**	**12.9**	**13.3**	**538.0**	**514.2**	**517.0**
Kratovo	**11.4**	**11.6**	**11.8**	**708.4**	**699.4**	**705.5**
K. Palanka	**10.2**	**10.0**	**10.6**	**656.5**	**623.0**	**655.1**
Kruševo	**8.2**	**8.4**	**8.7**	**815.1**	**799.9**	**808.5**
Kumanovo	**11.8**	**11.6**	**11.8**	**549.2**	**522.5**	**517.0**
Lazaropole	**6.8**	**6.7**	**6.8**	**1065.0**	**1068.0**	**1067.3**
N. Dojran	**14.1**	**14.0**	**14.5**	**625.4**	**630.0**	**654.0**
Ohrid	**11.1**	**11.1**	**11.6**	**698.3**	**696.0**	**693.1**
P. Šapka	**4.7**	**4.8**	**5.0**	**991.0**	**1000.7**	**995.5**
Prilep	**11.2**	**11.1**	**11.8**	**575.9**	**550.3**	**540.0**
Radoviš	**12.3**	**12.3**	**12.7**	**520.4**	**452.3**	**470.0**
Resen	**9.5**	**9.5**	**10.0**	**715.2**	**710.5**	**715.0**
Štip	**12.6**	**12.6**	**13.4**	**475.6**	**472.0**	**472.2**
Skopje	**12.2**	**12.1**	**12.6**	**514.8**	**504.0**	**500.8**
Sk-Petrov.	**12.0**	**-**	**12.4**	**504.4**	**-**	**508.5**
S. Glava	**-0.4**	**-**	**1.1**	**817.6**	**791.4**	**798.5**
Strumica	**12.7**	**12.7**	**13.4**	**567.4**	**560.7**	**515.5**
Tetovo	**11.0**	**10.8**	**11.5**	**783.8**	**719.0**	**742.0**
Valandovo	**14.5**	**14.2**	**14.6**	**642.6**	**610.8**	**589.0**
Veles	**13.3**	**13.2**	**14.0**	**442.6**	**440.0**	**447.0**
Average	***11.0***	***11.2***	***11.5***	***654.3***	***648.3***	***631.9***

Iso-T and Iso-P are extracted temp. and precip. data from our interpolated model.
Source: P 51-80 Lazarevski, 1993; P 61-90 Zikov et al, 1997; Filipovski et al., 1996;
*Data for the period 1985-2014 are collected through the various sources indicated bellow and they are not official by HMS of RM:
Environmental statistics, SSO-Skopje; for the period 1994-2013 (8 stations);
http://en.climate-data.org; for the period 2001-2012 (6 stations);
http://www.weatherbase.com; for the period 1981-2010 (7 stations);
http://www7.ncdc.noaa.gov/CDO; for the period 1985-2014 (6 stations);

Compared with data from the meteorological stations, mean precipitation inaccuracy of the WorldClim is 13.9%, while for our 60 m model it is 6.8%. Mean temperature inaccuracy is larger in both models: 24.5% for WorldClim vs. 15.4% for our model. The higher inaccuracy in WorldClim model is due to the much lower resolution (about 1 km), coarser selection of stations and the different period of 1950-2000 vs. 1961-1990 in our model. However, keep in mind the global coverage, WorldClim model for Macedonia is well tolerable.

Table 2. Mean real temperature (Real-T) and precipitation (Real-P) data (period 1951-1980) vs. data from the raster (grid) models.

	Real-T	**Iso-T**	**WClim-T**	**Real-P**	**Iso-P**	**WClim-P**	**Iso-T/R-T**	**WCl-T/R-T**	**Iso-P/R-P**	**WCl-P/R-P**
Berovo	**8.7**	9.6	9.4	**647.2**	711.1	525.2	0.08	0.10	0.09	0.23
Bitola	**11.0**	10.9	11.3	**599.8**	641.6	626.7	0.03	0.01	0.07	0.04
Brod	**10.7**	11.0	11.2	**735.1**	700.5	661.6	0.05	0.02	0.05	0.11
Debar	**11.8**	10.0	11.5	**872.2**	814.3	980.8	0.02	0.15	0.07	0.11
Delčevo	**10.6**	10.9	11.0	**570.1**	628.5	500.7	0.04	0.03	0.09	0.14
D. Kapija	**13.8**	13.5	13.8	**586.7**	546.9	456.7	0.00	0.02	0.07	0.28
Ergelija	**12.9**	12.5	13.1	**471.9**	505.1	476.0	0.01	0.03	0.07	0.01
Gevgelija	**14.0**	14.6	14.1	**675.5**	554.4	444.1	0.01	0.04	0.22	0.52
Kavadarci	**13.6**	12.8	13.6	**476.7**	499.8	476.5	0.00	0.06	0.05	0.00
Kičevo	**10.8**	11.0	11.2	**786.7**	734.1	761.5	0.04	0.02	0.07	0.03
Kočani	**12.9**	12.0	12.9	**538.0**	571.5	477.2	0.00	0.07	0.06	0.13
Kratovo	**11.4**	9.6	11.3	**708.4**	729.7	525.1	0.01	0.16	0.03	0.35
K. Palanka	**10.2**	10.3	10.7	**656.5**	681.1	513.4	0.05	0.01	0.04	0.28
Kruševo	**8.2**	8.1	8.6	**815.1**	838.6	748.7	0.04	0.01	0.03	0.09
Kumanovo	**11.8**	11.8	12.3	**549.2**	554.9	517.1	0.04	0.00	0.01	0.06
Lazaropole	**6.8**	7.1	7.2	**1065.0**	997.4	1023.1	0.05	0.04	0.07	0.04
N. Dojran	**14.1**	14.2	14.1	**625.4**	551.8	449.8	0.00	0.01	0.13	0.39
Ohrid	**11.1**	11.3	11.3	**698.3**	707.8	822.8	0.01	0.02	0.01	0.15
P. Šapka	**4.7**	4.0	4.8	**991.0**	1006.0	998.4	0.03	0.15	0.01	0.01
Prilep	**11.2**	10.5	11.4	**575.9**	637.3	571.7	0.02	0.06	0.10	0.01
Radoviš	**12.3**	12.0	12.4	**520.4**	569.3	473.8	0.01	0.03	0.09	0.10
Resen	**9.5**	10.0	9.9	**715.2**	747.5	765.0	0.04	0.05	0.04	0.07
Štip	**12.6**	12.5	12.8	**475.6**	517.7	471.0	0.02	0.01	0.08	0.01
Skopje	**12.2**	12.3	12.6	**514.8**	525.1	559.3	0.04	0.00	0.02	0.08
Sk-Petrov.	**12.0**	12.4	12.6	**504.4**	510.6	508.1	0.05	0.03	0.01	0.01
S. Glava	**-0.4**	2.0	1.1	**817.6**	944.8	939.5	3.84	6.03	0.13	0.13
Strumica	**12.7**	13.4	13.0	**567.4**	543.2	458.8	0.02	0.06	0.04	0.24
Tetovo	**11.0**	11.2	11.6	**783.8**	703.4	748.6	0.05	0.01	0.11	0.05
Valandovo	**14.5**	13.5	14.3	**642.6**	569.4	455.5	0.02	0.07	0.13	0.41
Veles	**13.3**	12.8	13.5	**442.6**	464.8	491.4	0.02	0.03	0.05	0.10
Average	***11.0***	***10.9***	***11.3***	***654.3***	***656.9***	***614.3***	***0.15***	***0.24***	***0.07***	***0.14***
Sum	**-**	**-**	**-**	**-**	**-**	**-**	***4.63***	***7.34***	***2.04***	***4.17***

Source: Lazarevski, 1993. Iso-T and Iso-P are extracted temperature and precipitation data from our interpolated model.

With further update (official data for the period 1981-2010) even more relevant and accurate model can be generated and used for comparison with this model. However, because of transformations of meteorological service of the Republic of Macedonia in the period 1991-1998, these data must be carefully taken into consideration. Analyses of preliminary data for the 30-year period 1985-2014 (Table 1) show gradual rising of mean temperatures (0.1-0.5°C) in regard to the previous 30-year periods (1951-1980 and 1961-1990).

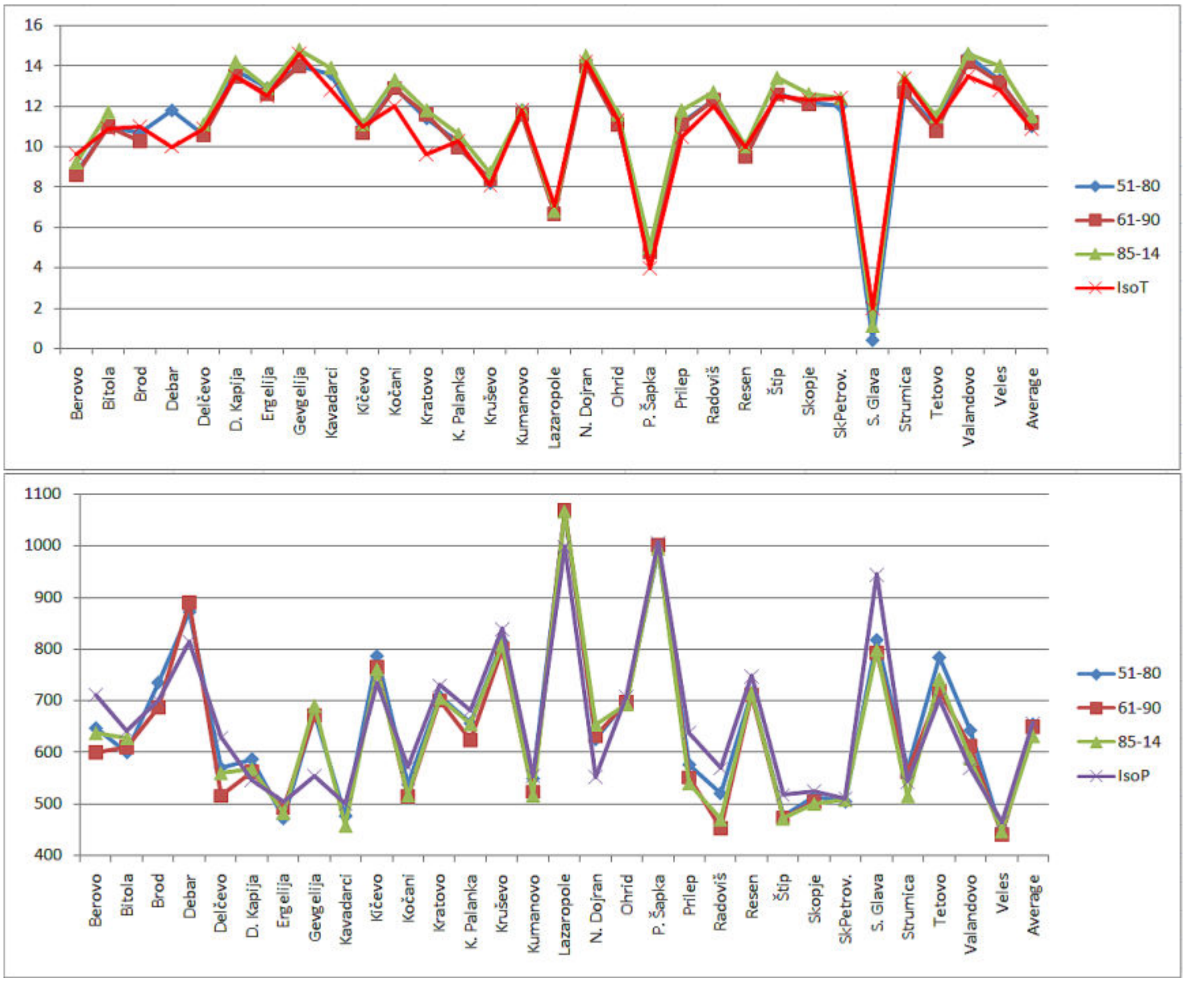

Figure 1: Graph of the mean temperatures and precipitations for different periods vs. intersected model values (IsoT and IsoP).

However, situation with precipitations is more complex because on the most stations they are slightly higher or almost the same with the previous periods. That is especially evident when data for the last 20 years (1995-2014) are taken into account. It is contrary to the previously accepted assumptions and scenarios that precipitations in Macedonia will gradually and significantly decrease in the period 2001-2050 compared to 1961-1990 (Bergant, 2006). It is still possible that the last decade is only transient wet period. Thus, climate data (1961-1990) used for the mean temperature and precipitation model of Macedonia can be assumed as generally relevant even nowadays (Fig. 1).

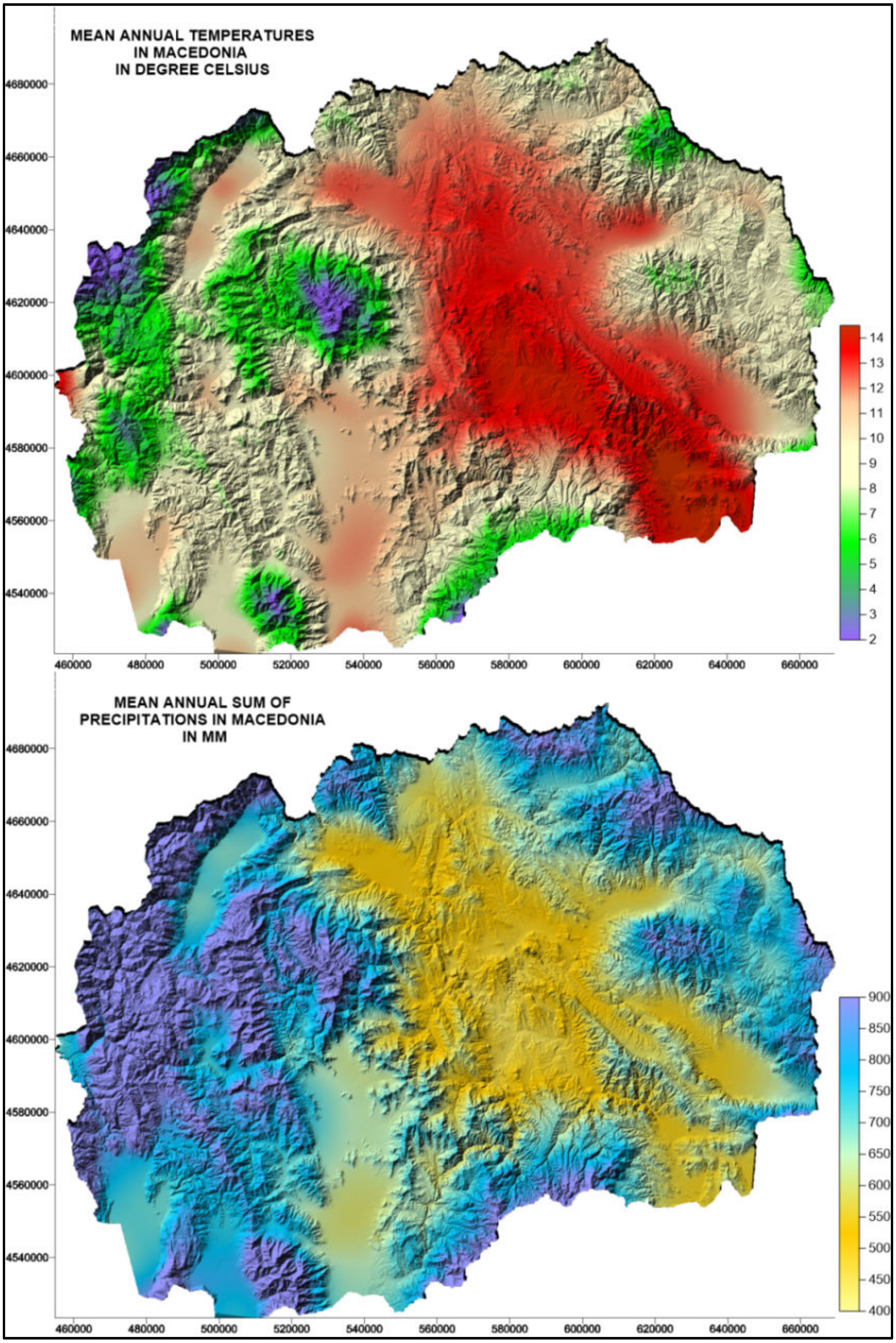

Figure 2: Digital mean temperature and precipitations map of Macedonia (1961-1990) with 100 m resolution.

CONCLUSION

In this paper, an approach of GIS-based modelling of mean annual temperature and precipitation in Macedonia is presented. The approach is based on the vertical temperature and precipitation gradients calculated from the 30 meteorological stations in the country (about 1 station on 850 km^2) and implemented over detailed 15-m DEM. Aside relatively coarse meteo-stations density, final raster models show very good accuracy when compared to previous models and iso-maps. That is because of model normalization with real (measured) data which is made in the second stage of the procedure. However, for even better accuracy, more precise vertical regressions must be calculated, with inclusion of data from the newer automatic gauges with more than 5 years of records. Further, with similar approach it is possible to produce models of other climate parameters and time periods: average minimal and maximal temperatures, extreme precipitations and temperatures, seasonal averages etc. The aplicability of these raster grids highly increase in many fields of modelling: from potential natural hazards to applications in agriculture, forestry, climate change management etc.

NOTE: Raster data in geotiff format can be downloaded from: www.igeografija.mk/geodata.htm

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ДИГИТАЛНИ МОДЕЛИ НА ПРОСЕЧНИТЕ ГОДИШНИ ТЕМПЕРАТУРИ И ВРНЕЖИ ВО РЕПУБЛИКА МАКЕДОНИЈА

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И З В О Д

Во овој труд е претставен пример на ГИС базирано моделирање на просечната температура и просечните врнежи во Република Македонија. Пристапот е заснован на користење на вертикални температурни градиенти и вертикални градиенти на врнежи пресметани од 30 метеоролошки станици (1 станица на 850 km^2). Овие податоци се нанесени преку детален 15 m дигитален висински модел. Без оглед на релативно ретката распределба на метеоролошките станици, добиените дигитални модели покажуваат многу подобра точност во однос на претходно постоечките модели и изо-карти. Таквата прецизност е резултат на тоа што интерполираните вредности со помош на градиентите се нормализирани (прецизирани) со реални податоци од метеоролошките станици. Сепак, за да се постигне уште подобра точност, неопходно е да се утврди прецизна вертикална регресија која ќе ги земе предвид податоците од автоматските станици со подолг период на мерење. На ваков начин, освен просечните годишни вредности можат да се добијат и многу други климатски параметри како: просечни минимални и максимални температури, екстремни врнежи и екстремни температури, сезонски просеци и друго. Можноста за примена на вакви модели во последно време станува сè поголема и тоа во различни апликативни области, од утврдување на потенцијални природни хазарди, преку примена на земјоделството, шумарството, климатските промени и други.